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Research article

Options for environmental regulation policy under China's carbon peaking target: Energy supply policy or carbon tax policy?

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ABSTRACT

China plans to achieve the carbon peaking target by 2030 and will maybe implement a series of environmental regulation policies, primarily including energy supply policy (such as coal consumption constraint and non-fossil energy development) and carbon tax policy. This paper simulates these policies using a computable general equilibrium model. The simulation results indicate that carbon tax policy has a finite impact on the economy, the emissions reduction effect is also limited and carbon tax policy alone is insufficient to achieve China's 2030 carbon peaking target. The coal consumption constraint policy has a good emissions reduction effect, but is not conducive to economic growth. The non-fossil energy development policy can increase energy supply and promote economic growth, but the emissions reduction effect is inadequate. In general, the simultaneous implementation of the coal consumption constraint and non-fossil energy development policies could not only achieve the carbon peaking goal, but also narrow the energy gap and reduce pressure on economic growth. However, it is notable that if carbon tax policy and energy supply policy are implemented simultaneously, the emissions reduction effect of carbon tax policy would be significantly reduced; therefore, it is likely that no carbon tax will be levied in China.

1. Introduction

At the UN Climate Ambition Summit in December 2020, the Chinese government announced the goal of reaching peak carbon dioxide (CO_2) emissions by 2030. To achieve this goal, the Chinese government plans to adopt a series of environmental regulation policies, such as coal consumption constraint (CCC), non-fossil energy development (NED) and other energy supply policies. At the same time, many scholars [1,2] have suggested that China should impose a carbon tax to reduce carbon emissions.

Environmental regulation policies are usually divided into many types. This study primarily focuses on energy supply policies and carbon tax policy. Both types of policies can reduce carbon emissions, but both also dampen economic growth, posing a dilemma for China [3]. The difference between the two types of policies is that energy supply policy is more effective in reducing emissions but more damaging to the economy, whereas carbon tax policy enables more flexible production adjustment and innovation mechanisms for firms [4], with less negative impact on the economy, but the environmental effect may be relatively weak. To achieve carbon peaking while considering the need for economic growth, what kind of environmental regulation policies will China choose in the future? What impact will such environmental regulation policies have on China's carbon emissions and economy? The answer to this question is extremely important. This article attempts to answer these questions and provide very important suggestions for China's

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energy policy formulation, which will hopefully help China achieve its carbon peaking goal by 2030 while minimising the adverse impact on the economy.

This paper improves on existing literature in three ways. First, this paper uses the dynamic computable general equilibrium (CGE) model to analyse multiple energy supply policies and carbon tax policies simultaneously. Current research on environmental regulation policies is primarily biased towards a single policy. Second, this paper measures the environmental and economic effects of environmental regulation policies. At present, there is considerable research regarding the environmental effects of environmental regulation and the research on economic effects are mainly focused on total factor productivity and enterprise performance. This paper attempts to systematically analyse the environmental and economic effects of environmental regulation policies, especially the impact of policy changes on economic growth and institutional income. Third, this paper attempts to propose the environmental regulation policies that China should adopt to achieve the carbon peaking target by 2030 and measure the possible economic impact of such environmental regulation policies.

The remainder of this paper is arranged as follows. Section 2 presents the literature review regarding environmental regulation policies. Section 3 constructs a general equilibrium analysis model of environmental regulation policies. Section 4 designs the simulation schemes for energy supply and carbon tax policies. Section 5 analyses the simulation results for each policy, comparing the economic and environmental effects of each policy and finally draws conclusions and proposed policy implications in section 6.

2. Literature review

Environmental regulations can be defined as the combination of administrative, economic, and moral constraints imposed by the government [5]. Among these, research on command-and-control policies is relatively extensive. The command-and-control policies mainly include energy supply control policy, carbon intensity reduction targets and low-carbon city pilot policies in China. The first regulation is energy supply policy. China's energy consumption structure has the characteristics of 'rich coal and light gas' [6], it is advisable to adjust energy structure by limiting coal supply and promoting other energies' supplies, such as hydropower, nuclear power, wind power, solar and other clean energy sources [7–9]. This policy can dramatically decrease CO2 emissions [10], but also have a negative impact on economic growth [11]. The second regulation is carbon intensity reduction targets (CIRTs). Moderate CIRTs can prompt low-carbon energy consumption, while stricter carbon regulations fail to optimise energy structure and it is not feasible to achieve carbon neutralisation [12]. The third regulation is low-carbon city pilot (LCCP) policy. Undoubtedly, the LCCP policy can effectively curb firms' coal consumption [13]; however, it also has side effects. For instance, resource-based cities are trapped in a resource dependency dilemma [14], urban non-green innovation tends to be crowded out [15] and the positive effect is not durable [16]. Considering that China is currently implementing a strong energy supply policy, this paper focuses on simulating the impact of this policy implementation on carbon emissions and economic growth.

There are also many studies regarding carbon tax policy. Numerous scholars agree that carbon tax can decrease CO2 emissions [17, 18]. Carbon tax can save energy, stimulate NED and reduce CO2 emissions, but it also exerts a negative impact on economic growth [19]. A lot of scholars argue that carbon tax should be set at a low level to realise the reduction target at the lowest economic cost [20, 21]. In contrast, some scholars assert that low-carbon taxes do not have an effect on carbon emissions reduction and only higher levels of carbon tax can do so [22]. Other types of market-based regulations include carbon emissions trading [23], electric vehicle subsidies [24], energy price control policy [25], and trading emission system [26].

In the research comparing the effects of these two types of environmental regulation policies, there are three prevalent opinions regarding these two environmental regulations. Firstly, some literature suggests that carbon tax policy is more efficient than energy supply policy. Carbon tax policy is considered more flexible in regulating enterprise production and innovation, which can significantly enhance productivity [4], while energy supply policy brings rapid reductions in pollution at the cost of economic growth. Furthermore, some studies contend that energy supply policy would inhibit firms' total factor productivity and technology innovation [27–29], while carbon tax policy can promote them [30]. The second strand is on the contrary. Energy supply policy is the strongest way to reduce energy consumption, followed by economic tools [31]. Carbon tax policy exerts negative effect on GTFP by inhibiting technological innovation and reducing industrial structural, scale, and resources allocation efficiencies [32]. The final strand contends that both energy supply policy and carbon tax policy have pros and cons. Energy supply policy favours emissions reduction but has no significant effect on technological progress [33], whereas carbon tax policy is found to favour technological progress and green development [34], but its effects on emissions reduction is relatively weak.

Based on the research findings, it is widely acknowledged by scholars that energy supply policy is capable of effectively reducing carbon emissions with relatively direct and predictable outcomes. However, there is a concern that it may also potentially harm economic efficiency. In contrast, carbon tax policy, which does not directly intervene in market operations and align more closely with economic principles, is expected to yield favourable economic outcomes. Nevertheless, the effectiveness of carbon tax policy in reducing carbon emissions varies depending on their specific design and implementation. Besides, scholars have not reached a consensus regarding the effects of different types of environmental regulation policies and most of the studies only examine the effect of a single environmental regulation policy. To achieve the carbon peaking goal, China's main environmental regulation policies are currently energy supply policies, such as CCC and NED. Many scholars also contend that carbon tax policy should be implemented. This paper uses the CGE model to systematically evaluate energy supply policy and carbon tax policy, comprehensively comparing and analysing the environmental and economic effects of these two types of policies to provide policy recommendations for China's subsequent environmental regulation reforms.

3. Theoretical model

To analyse the environmental and economic effects of the two types of environmental regulation policies, based on the assumptions of factor flow and market clearing in general equilibrium theory, this paper constructs a computable general equilibrium model of carbon tax policy and energy supply policy. The analysis framework of the computable general equilibrium model is shown in Fig. 1. The model has three characteristics. (1) The general CGE model adopts a simplified tax module, which only includes three types of tax: production tax, individual income tax and corporate income tax. In this paper, to explore the environmental and economic effects of carbon tax, production tax is subdivided into two categories of carbon tax and other production tax. (2) Usually, only two elements of labour and capital are included in the CGE input module. In this paper, the energy element is separated from the capital element. Referencing the statistical calibre of primary energy in the China Statistical Yearbook, the energy element is subdivided into four sub-elements of coal, oil, natural gas and non-fossil energy, among which non-fossil energy is composed of wind power, solar power, hydropower and nuclear power. The breakdown of energy factors provides the basis for modelling energy supply policies. (3) The output module measures the impact of different policies on CO_2 emissions. The core equations of the CGE model in this paper are presented below [35]. There are many basic CGE equations in this paper and for space reasons, only the main equations and variables are shown. All variables in the equations have time attributes and according to the general CGE formulation, all variables are omitted with the subscript *t*.

3.1. Production module

In contrast to the standard production module settings of the CGE model, this paper adds subdivided energy factors and related taxes in the value-added function to capture the mechanism of energy input, carbon tax and VAT in the production function. The value-added function adopts the Cobb–Douglas form, as shown in equation (1). The factor price equilibrium equation is shown in equations (2)–(4).

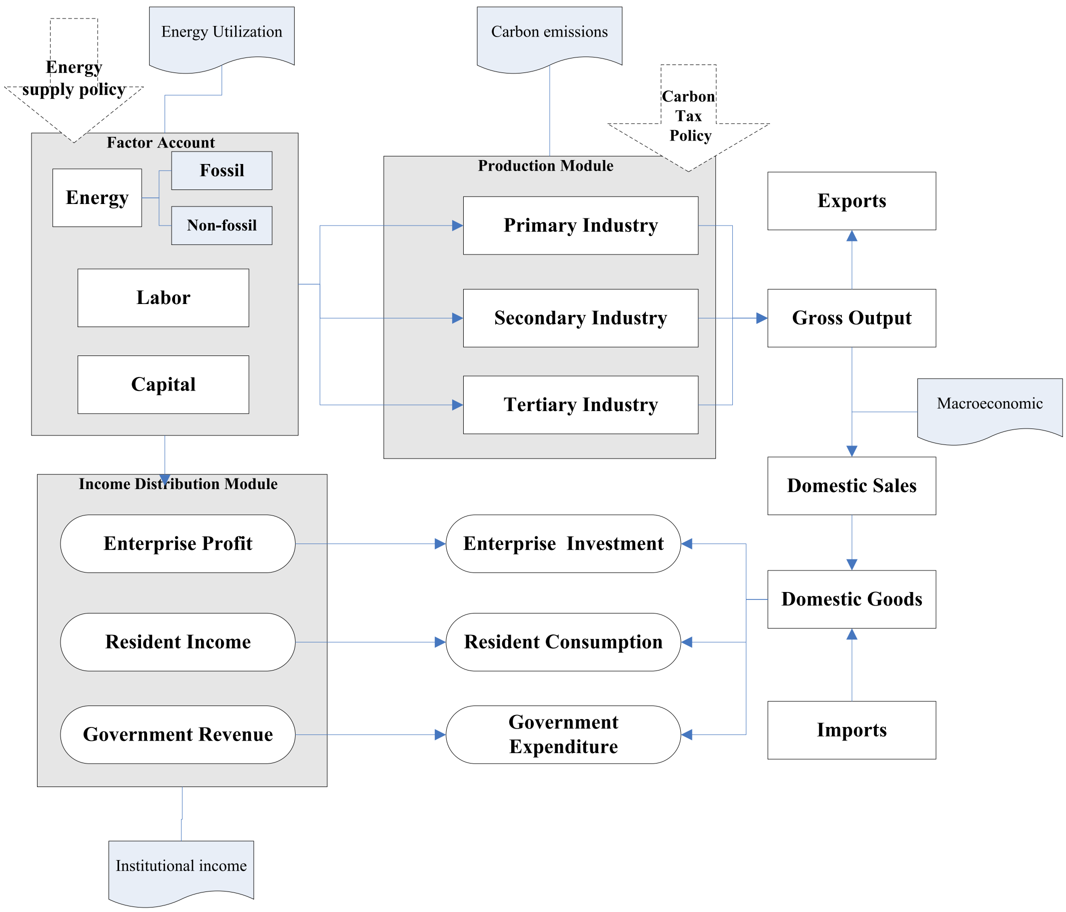

Fig. 1. Analysis framework of the computable general equilibrium model.

$$QVA_a = \alpha_a \bullet QLD_a^{\beta l_a} \bullet QKOD_a^{\beta k_a} \bullet \prod_{i=1}^{4} QKED_{i,a}^{\beta e_{i,a}} \tag{1}$$

$$WL \bullet QLD_a = \beta l_a \bullet PVA_a \bullet QVA_a \tag{2}$$

$$WKO \bullet QKOD_a = \beta k_a \bullet PVA_a \bullet QVA_a \tag{3}$$

$$WKE_i \bullet (1 + ct_i) \bullet QKED_{i,a} = \beta e_{i,a} \bullet PVA_a \bullet QVA_a \tag{4}$$

where the subscript a is sector's activity; QVA is the value-added component of the economy; QLD is the labour demand; $QKOD$ is the capital demand; $QKED_{i,a}$ is the demand for various types of primary energy elements in sector a; i is each type of primary energy, including coal, oil, natural gas and non-fossil energy; PVA is the price of added value; WL is the price of labour factors; WKO is the price of capital factors; WKE_i is the price of energy i; ct is the carbon tax rate; α is the production technology level of added value; βl is the elasticity coefficient of labour; βk is the elastic coefficient of capital and βe is the elastic coefficient of energy.

The carbon tax rate parameter is added in equation (4). When the carbon tax is imposed, it will first affect the various types of energy demand ($QKED_{i,a}$) in equation (4), which then affects the amount of added value in equation (1) and the amount of labour and capital demand will also change. Then, through equations (2) and (3), labour and capital factor prices are affected. The changes in the variables of the value-added function module will affect the modules of the commodity market and income distribution through the total output function and the changes in various market modules will eventually affect those of energy factor demand again. The changes in carbon emissions are calculated according to the carbon emissions coefficients of various energy sources.

3.2. Income distribution module

Enterprise income comes from capital and energy factor remuneration through the enterprise and government transfer payments. Enterprise income functions are as follows:

$$YENT = sh_{ek} \bullet WKO \bullet QKOS + sh_{ee} \bullet \sum\nolimits_i WKE_i \bullet QKES_i + tr_{eg} \tag{5}$$

$$ENTS = (1 - ti_e) \bullet YENT \tag{6}$$

where $YENT$ is the enterprise income; $QKOS$ is the supply of capital factors; $QKES_i$ is the supply of the i-th energy factor; sh_{ek} is the share of capital income allocated to the enterprise; sh_{ee} is the share of energy income allocated to the enterprise; tr_{eg} is the government's transfer payment income to enterprises; $ENTS$ is enterprise savings and ti_e is the enterprise income tax rate. Equation (5) indicates that changes in the energy factor supply quantity and energy prices will directly affect enterprises' income scale of. Equation (6) shows that changes in enterprise income, as the tax base of corporate income tax, will lead to changes in the scale of corporate income tax.

Household income comes from labour and capital factor remuneration and government transfer payments. The household income functions are as follows:

$$YH = WL \bullet QLS + WKO \bullet sh_{hk} \bullet QKOS + tr_{hg} \tag{7}$$

$$YD = YH - wt \bullet WL \bullet QLS - rt \bullet WKO \bullet sh_{hk} \bullet QKOS \tag{8}$$

where YH is household income; QLS is the supply of labour factors; YD is disposable income; sh_{hk} is the proportion of capital income distributed to households; tr_{hg} is the government transfer payment to a household and wt and rt are the labour and capital income tax rates, respectively. The carbon tax levy and changes in the quantity of energy supply will affect labour and capital factor prices, which will affect household income through equation (7). In equation (8), changes in household income will also affect the scale of personal income tax.

Government revenue (YG) consists of various types of tax revenue sources, including carbon tax, other production tax, personal income tax and corporate income tax. The collection of carbon tax will first directly affect the government's income as well as production, indirectly affecting other tax revenue through changes in the supply of capital and labour factors. The energy factors supply policies directly affect the quantity of energy supply and cause various tax revenue changes through production. The government revenue function is as follows.

$$YG = \sum_a tx_a \bullet PA_a \bullet QA_a + \sum_i \sum_a ct_i \bullet QKED_{i,a} + wt \bullet WL \bullet QLS + rt \bullet WKO \bullet sh_{hk} \bullet QKOS + ti_e \bullet YENT \tag{9}$$

where tx is other production tax rates and PA and QA are total output price and total output quantity, respectively.

3.3. Macro closure

Based on different economic theories, closure of the CGE macro model can be achieved in different ways. This paper constructs a dynamic module based on the neoclassical closure, including factor market, commodity market and capital investment market equilibrium [36]. The energy supply policy simulated in this paper must be integrated into the factor market equilibrium module. The equilibrium of the factor market implies that total demand of labour, capital and energy factors is equal to total supply and the markets for labour, capital and energy factors are all cleared. When implementing energy supply policies, corresponding energy factor supply variables must be defined as exogenous variables to change the equilibrium quantity of market clearing.

Referring to the usual setup of CGE models, this paper also considers the import and export modules. (1) In the export module, the distribution of domestically produced goods between domestic sales and exports is influenced by the relative levels of domestic and international prices, akin to a production possibility frontier. This relationship is represented in this paper using the CET (constant elasticity of transformation) function. (2) In the import module, the goods sold in the domestic market consist of both imported and domestically produced goods, which are not necessarily perfect substitutes. In CGE models, this relationship is typically represented using the CES function, known as the "Armington condition".

The above theoretical mechanism analysis demonstrates that both carbon tax levy and energy supply changes affect the value-added function, changing the price and equilibrium quantity of relevant energy and the energy use structure also subsequently changes, leading to changes in CO_2 emissions. Changes in the prices and quantities of factors are transmitted across the entire production module, which then affects the prices of and demand for various commodities. As a result, income distribution and commodity consumption also change and household, enterprise and government incomes vary with such changes. Accordingly, there are also changes in macroeconomic variables, such as economic growth.

4. Data, parameter calibration and simulation scenario setting

4.1. Base data and parameter calibration

The CGE model takes the social accounting matrix (SAM) as base data. Data from the China Input–Output Table, the China Statistical Yearbook, the China Tax Yearbook, the China Energy Statistical Yearbook, the China Environmental Statistical Yearbook and the National Bureau of Statistics were employed to construct the SAM in this paper, which describes the current characteristics of China's energy consumption and taxation system. This paper divides the production sector of the SAM into 15 industries according to three major industrial criteria: (1) The primary industry is agriculture. (2) The secondary industry is divided into manufacturing, utility supply,[1] and construction, which can be further subdivided into 11 industries. Of these, manufacturing includes the coal mining and washing industry, oil and gas mining industry, ferrous metal mining and dressing industry, non-ferrous metal mining and dressing industry, non-metallic mining and dressing industry, mining auxiliary activity industry, other manufacturing industry; utility supply includes electricity and heat production and supply industry, gas production and supply industry, water production and supply industry. (3) The tertiary industry is divided into wholesale and retail trade, transportation and other tertiary industries [37].

The main parameters of the CGE model in this paper are roughly divided into three categories. (1) The parameters of use hours of non-fossil energy power generation equipment are calculated based on the China Energy Big Data Report (2021) issued by China Power Media Corporation and the National Power Industry Statistics (2020) issued by the National Energy Administration. The annual operational hours for hydropower, nuclear power, wind power, and solar power generation in China are 3827 h, 7453 h, 2073 h, and 1281 h, respectively. (2) The CO_2 emissions parameters of various energy sources are based on the data from the China Energy Statistical Yearbook and the Intergovernmental Panel on Climate Change Guidelines for National Greenhouse Gas Inventories. The carbon emission coefficients for coal, petroleum, and natural gas are 1.9, 3.02, and 2.16 respectively. (3) Other parameters are handled according to the standard CGE method. Parameters, such as CES function substitution elasticity (0.2) and Armington elasticity (between 1.9 and 3), are all estimated values from other studies [38]. Share, scale and other variables in the CGE model function are calculated and adjusted using the SAM table data.

4.2. Scenario settings

This paper makes the following scenario settings for simulating the environmental regulation policy in China, as shown in Table 1. Scenarios 1 and 2 involve carbon tax policies. Scenarios 3 to 5 encompass energy supply policies, primarily guided by China's " Action Plan for Carbon Dioxide Peaking Before 2030". The plan's main objectives include strict control over coal consumption growth and increasing the share of non-fossil energy consumption. Therefore, this paper selects NED and CCC as representative policies for these scenarios. Scenarios 6 and 7 depict combined policies.

Scenario 1: a carbon tax is imposed on the carbon dioxide emitted by enterprises' production processes. Referencing relevant study, this article simulates a carbon tax of 40 Yuan/tonne [37]. A carbon tax can generate green dividends, improve the ecological environment and reduce CO_2 emissions. Considering that there are no other tax cuts, the new tax will reduce the efficiency of economic operations and inhibit economic growth.

Scenario 2: some countries in the world have higher carbon tax rates, such as Sweden's carbon tax rate of US$127/tonne, Finland's US$70/tonne and South Korea's US$22/tonne [39]. To observe the environmental and economic effects of high carbon tax rate on China, this paper establishes a high carbon tax rate scenario with a tax rate of 120 Yuan/tonne.

Scenario 3: according to China's carbon peaking plan, 'by 2030, the total installed capacity of wind power and solar power will

[1] According to the industry classification standard of "China Statistical Yearbook", the full name here should be "electricity, heat, gas and water production and supply industry", which in this paper is abbreviated as "utility supply".

Table 1
Scenario settings for China's environmental regulation policy.

Policy type		Scenario	Content of policy
Carbon tax policy	Normal tax rate	Scenario 1	Carbon tax: 40 Yuan/tonne of CO_2
	High tax rate	Scenario 2	Carbon tax: 120 Yuan/tonne of CO_2
Energy supply policy	NED	Scenario 3	● Wind power: 35 million kilowatts of new installed capacity per year. ● Solar power: 31.51 million kilowatts of new installed capacity per year. ● Hydropower: 9.5225 million kilowatts of new installed capacity per year. ● Nuclear power: 4.0625 million kilowatts of new installed capacity per year.
	CCC	Scenario 4	No increment of coal consumption from 2021 to 2030, with annual consumption decreasing by 1 % from the previous year after 2031.
		Scenario 5	No increment of coal consumption from 2021 to 2030, with annual consumption decreasing by 1.5 % from the previous year after 2031.
Combined policy		Scenario 6	Scenario 1 + Scenario 3 + Scenario 5
		Scenario 7	Scenario 3 + Scenario 5

reach more than 1.2 billion kilowatts'. To achieve this goal, wind power and solar power generation must add 35 million and 31.51 million kilowatts of new installed capacity each year, respectively. The average annual installed capacity of hydropower and nuclear power from 2016 to 2020 was 9.5225 and 4.0625 million kilowatts, respectively. In terms of policy continuity, it is assumed that the annual newly installed capacity of hydropower and nuclear power will remain unchanged in the future.

Scenario 4: according to China's "Action Plan for Carbon Dioxide Peaking Before 2030″ and China's carbon peak target for 2030, China will strictly CCC from 2021 to 2030; therefore, this paper assumes that China's coal consumption will remain at the level of 2020 before 2030 and that annual coal consumption after 2031 will decrease by 1 % compared with the previous year.

Scenario 5: considering limiting the amount of coal consumption will directly affect the scale of carbon emissions. Referencing relevant study [40], to test the impact of coal consumption on the carbon emissions inflection point, this paper assumes that China's coal consumption will remain at 2020 levels by 2030 and annual coal consumption after 2031 will decrease by 1.5 % compared with the previous year, which is higher than Scenario 4.

Scenario 6: considering that each scenario has advantages and disadvantages [41], to observe the environmental and economic effects of various policies, this paper attempts to combine the simulated policies of Scenarios 1, 3 and 5 to obtain the predicted effect of the combined policies.

Scenario 7: to observe the role of carbon tax policy in combined policies, this paper constructs an executive-order combined policy scenario, integrating the simulated policies of Scenarios 3 and 5, comparing the simulation results with Scenario 6.

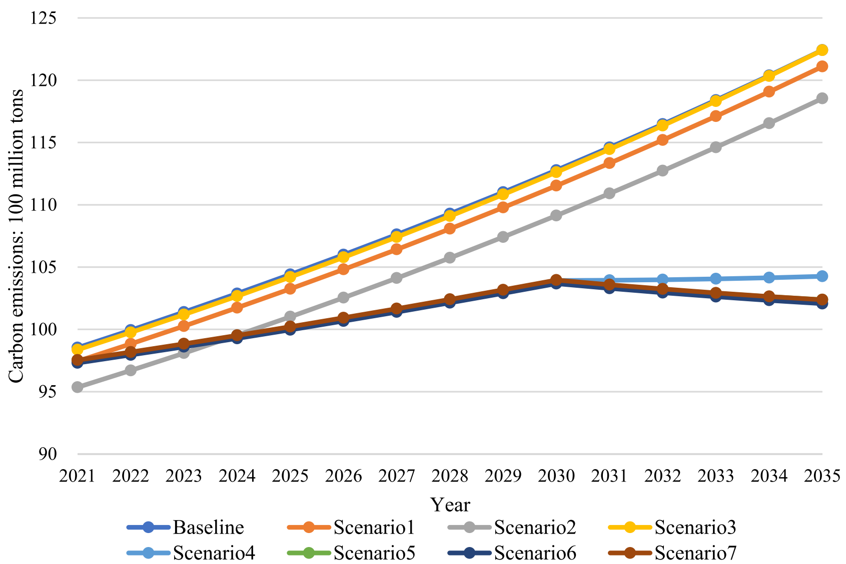

Fig. 2. Changes in China's carbon emissions under different policy scenarios (100 million tonnes).

5. Simulation results analysis

Based on the above scenarios simulating carbon tax policies and energy supply policies, this paper obtains the predicted environmental and economic effects of the policies from the perspectives of carbon emissions, energy use, macroeconomics and institutional income.

5.1. Carbon emissions

The simulation results of changes in China's carbon emissions under different policy scenarios are shown in Fig. 2. In Scenarios 1 and 2, carbon emissions decline slightly relative to the baseline scenario, but the trend of rising emissions remains unchanged, with no inflection point in the emissions trajectory. The imposition of carbon tax (Scenario 1) can reduce carbon emissions. By 2030 and 2035, carbon emissions will decrease by about 1.10 % and 1.08 % compared to the baseline scenario, while the growth trend of emissions is similar to the baseline scenario. In Scenario 2, the increase in the carbon tax rate enhances the tax's emissions reduction effect. By 2030 and 2035, carbon emissions will decrease by about 3.23 % and 3.17 % compared to the baseline scenario, respectively. According to our calculation, carbon emissions will decrease by about 1 % for every 40 Yuan/tonne increase in carbon tax.

In Scenario 3, NED alone will not significantly reduce carbon emissions. In the baseline scenario, China's carbon emissions will reach 11.278 billion tonnes and 12.242 billion tonnes in 2030 and 2035, respectively. In Scenario 3, NED has little impact on carbon emissions, which will decrease by 0.14 % and 0.01 % in 2030 and 2035, respectively. It can be seen that if China only develops new energy sources without limiting coal consumption, the reduction of carbon emissions is likely to be limited.

CCC can significantly reduce carbon emissions, but only when coal consumption falls by about 1.5 % will China be able to meet its 2030 carbon peaking target. In Scenarios 4 and 5, China's carbon emissions in 2030 will be 10.392 billion tonnes, a decrease of 7.85 % compared with the baseline scenario. In Scenario 4, although coal consumption is reduced, carbon emissions are still slowly rising; therefore, carbon peaking cannot be achieved. When the annual coal consumption decreases by 1.5 % from the previous year after 2031 (Scenario 5), carbon emissions will begin to decrease year by year; hence, the carbon peaking target can be achieved in 2030.

The combined policies are all capable of achieving the carbon peaking target by 2030; however, carbon tax policies' reduction effect will be greatly weakened. In Scenarios 6 and 7, China's carbon emissions in 2030 will be about 10.367 billion tonnes and 10.396 million tonnes, respectively, a decrease of 8.07 % and 7.82 % from the baseline scenario. In the following years, carbon emissions decrease year by year and by 2035, carbon emissions will be about 10.207 billion tonnes and 10.238 billion tonnes, respectively. Both combined policies can successfully achieve the carbon peaking target, but the emissions reduction effects of Scenarios 6 and 7 are close, indicating that the emissions reduction effect of carbon tax policy would be greatly reduced when carbon tax and energy supply policies are superimposed.

5.2. Energy use

The implementation of a carbon tax policy will diminish the demand for energy, with coal and oil consumption declining more significantly. The change rate of energy usage under different policy scenarios relative to the baseline scenario is shown in Table 2. In Scenario 1, China's total energy consumption in 2030 and 2035 decreases by 0.84 % and 0.78 %, respectively. In Scenario 2, China's total energy consumption in 2030 and 2035 decreases by 2.45 % and 2.28 %, respectively, with a much steeper decline than Scenario 1. The demand for coal and oil demand declines significantly, with coal and oil consumption falling by 3.20 % and 3.45 % in 2030, respectively.

The NED raises total energy consumption, but the substitution effect is relatively limited. In Scenario 3, non-fossil energy

Table 2
Change rate of energy usage under different policy scenarios relative to the baseline scenario.

Scenario	2030					2035				
	Total	Coal	Oil	Natural gas	Non-fossil energy	Total	Coal	Oil	Natural gas	Non-fossil energy
Baseline (100 million tonnes)	63.76	31.49	12.53	7.76	11.98	74.34	33.41	14.38	11.05	15.49
Scenario 1	−0.84 %	−1.09 %	−1.18 %	−0.22 %	−0.20 %	−0.78 %	−1.07 %	−1.17 %	−0.21 %	−0.19 %
Scenario 2	−2.45 %	−3.20 %	−3.45 %	−0.66 %	−0.59 %	−2.28 %	−3.13 %	−3.44 %	−0.60 %	−0.56 %
Scenario 3	1.81 %	−0.23 %	0.13 %	−0.02 %	10.13 %	0.46 %	−0.03 %	0.05 %	0.01 %	2.21 %
Scenario 4	−4.82 %	−10.18 %	−0.83 %	1.71 %	0.89 %	−8.08 %	−19.49 %	−2.15 %	4.21 %	2.24 %
Scenario 5	−4.82 %	−10.18 %	−0.83 %	1.71 %	0.89 %	−8.89 %	−21.50 %	−2.42 %	4.76 %	2.54 %
Scenario 6	−3.32 %	−10.18 %	−1.75 %	1.27 %	10.13 %	−9.20 %	−21.50 %	−3.40 %	4.42 %	2.21 %
Scenario 7	−3.06 %	−10.18 %	−0.69 %	1.65 %	10.13 %	−8.95 %	−21.50 %	−2.40 %	4.81 %	2.21 %

consumption will reach 131.9 thousand tonnes and 158.3 thousand tonnes in 2030 and 2035, respectively, with an increase of 10.13 % and 2.21 % compared with the baseline scenario and total energy consumption increases by 1.81 % and 0.46 %, respectively. By then, the proportion of non-fossil energy consumption will be 20.32 % and 21.20 %, respectively. In Scenario 3, the proportion of fossil energy consumption does not notably change and the energy consumption structure remains relatively stable, indicating that expanding the supply of non-fossil energy alone has a limited substitution effect and cannot significantly inhibit the consumption of fossil energy.

Simply CCC will result in a significant drop in total energy consumption. In Scenario 5, coal consumption will decrease by 10.18 % and 21.50 % in 2030 and 2035, respectively; resulting in a decrease of 4.82 % and 8.89 % in total energy consumption compared with the baseline scenario and energy consumption declines considerably.

The combined policies can slightly alleviate the energy supply gap caused by coal supply constraints. In the combined policies, coal consumption falls sharply while non-fossil energy consumption shows an increase; thus, the decline in total energy consumption narrows. In Scenarios 6 and 7, the total energy consumption in 2030 will decrease by 3.32 % and 3.06 %, respectively, which is less than the pure coal consumption restriction policy.

5.3. Macroeconomic

The carbon tax policy will inhibit economic growth, with each 40 Yuan/tonne of carbon tax causing a 0.22 % decline in China's GDP. The change rate of economic growth under different policy scenarios relative to the baseline scenario is shown in Table 3. In the baseline scenario, China's GDP will reach 166.44 trillion Yuan in 2030 and 217.55 trillion Yuan in 2035. After imposing a carbon tax of 40 Yuan/tonne (Scenario 1), GDP in 2030 and 2035 will drop by 0.22 % and 0.24 %, respectively; from the perspective of industry, the carbon tax will suppresses the economies of primary and secondary industries, while the tertiary industry will grow slightly, primarily because of the high proportion of energy demand in the primary and secondary industries; regarding the industry breakdown, the manufacturing and construction sectors in the secondary industry will have a greater decline in value added, declining by 0.50 % and 0.65 %, respectively (Table 4), and the transportation, wholesale and retail sectors in the tertiary industry will also decline in value added, while the other service industries will increase. Raising the carbon tax rate (Scenario 2) will reduce China's GDP by 0.64 % and 0.72 % in 2030 and 2035, respectively, indicating that the inhibitory effect on the economy is significantly enhanced with the increase in the carbon tax rate.

Economic growth can be boosted by NED. In Scenario 3, China's GDP will increase by 0.26 % and 0.08 % in 2030 and 2035, respectively. The growth rates are similar across industries, indicating that the expansion of non-fossil energy investment can promote economic growth, but the increase will eventually weaken.

CCC would significantly curb economic growth. In Scenario 5, China's GDP will drop by 0.77 % and 1.98 % in 2030 and 2035, respectively, of which the secondary sector experiences the largest decline, falling by 0.86 % and 2.23 %, respectively. In terms of the industry breakdown, CCC has the largest impact on manufacturing and a smaller impact on utility supply. This demonstrates that the reduction of coal supply has obvious adverse effects on economic growth, with the greatest impact on the manufacturing industry.

The negative impact on the economy is more pronounced for the combined policy with carbon tax, while the combined policy without carbon tax can slightly alleviate the inhibitory effect on economic growth. In Scenario 6, China's GDP will drop by 0.64 % and 2.09 % in 2030 and 2035, respectively. The combined policy containing a carbon tax has a stronger inhibitory effect on economic growth. In Scenario 7, China's GDP will drop by 0.51 % and 1.96 % in 2030 and 2035, respectively. The combined policy without carbon tax has better economic effect than the combined policies with carbon tax.

Table 3
Change rate of economic growth under different policy scenarios relative to the baseline scenario.

Scenario	2030				2035			
	GDP	Primary industry	Secondary industry	Tertiary industry	GDP	Primary industry	Secondary industry	Tertiary industry
Baseline (100 million tonnes)	166.64	5.08	89.26	72.30	217.55	6.64	116.27	94.65
Scenario 1	−0.22 %	−0.24 %	−0.57 %	0.23 %	−0.24 %	−0.30 %	−0.52 %	0.11 %
Scenario 2	−0.64 %	−0.72 %	−1.68 %	0.66 %	−0.72 %	−0.88 %	−1.54 %	0.31 %
Scenario 3	0.26 %	0.25 %	0.27 %	0.25 %	0.08 %	0.09 %	0.08 %	0.09 %
Scenario 4	−0.77 %	−0.70 %	−0.86 %	−0.66 %	−1.77 %	−1.68 %	−1.99 %	−1.50 %
Scenario 5	−0.77 %	−0.70 %	−0.86 %	−0.66 %	−1.98 %	−1.88 %	−2.23 %	−1.68 %
Scenario 6	−0.64 %	−0.61 %	−1.04 %	−0.14 %	−2.09 %	−2.06 %	−2.57 %	−1.51 %
Scenario 7	−0.51 %	−0.45 %	−0.60 %	−0.42 %	−1.96 %	−1.85 %	−2.22 %	−1.65 %

Table 4
Change rate of major industries' added value under different policy scenarios relative to the baseline scenario.

Year	Industry	Baseline (100 million tonnes)	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
2030	Manufacturing industry	42.77	−0.50 %	−1.47 %	0.34 %	−1.16 %	−1.16 %	−1.17 %	−0.82 %
	Utility supply industry	1.95	−0.36 %	−1.06 %	0.13 %	0.94 %	0.94 %	0.60 %	1.03 %
	Construction industry	44.54	−0.65 %	−1.91 %	0.20 %	−0.65 %	−0.65 %	−0.99 %	−0.45 %
	Transportation industry	4.98	−0.12 %	−0.35 %	0.13 %	−0.14 %	−0.14 %	−0.12 %	−0.02 %
	Wholesale and retail industry	10.98	−0.35 %	−1.02 %	0.17 %	−0.32 %	−0.32 %	−0.45 %	−0.16 %
	Other third-party service industries	56.34	0.37 %	1.07 %	0.28 %	−0.77 %	−0.77 %	−0.08 %	−0.50 %
2035	Manufacturing industry	55.17	−0.50 %	−1.46 %	0.11 %	−2.74 %	−3.07 %	−3.36 %	−3.06 %
	Utility supply industry	2.64	−0.34 %	−1.01 %	0.05 %	2.56 %	2.91 %	2.53 %	2.95 %
	Construction industry	58.45	−0.56 %	−1.64 %	0.06 %	−1.49 %	−1.67 %	−2.05 %	−1.66 %
	Transportation industry	6.62	−0.18 %	−0.52 %	0.06 %	−0.32 %	−0.35 %	−0.46 %	−0.31 %
	Wholesale and retail industry	14.52	−0.37 %	−1.08 %	0.07 %	−0.68 %	−0.75 %	−1.01 %	−0.71 %
	Other third-party service industries	73.50	0.23 %	0.66 %	0.09 %	−1.77 %	−1.98 %	−1.70 %	−1.96 %

5.4. *Institutional income*

The carbon tax levy can increase government tax revenue, but it can also lead to a decline in household and enterprise income. The change rate of economic growth under different policy scenarios relative to the baseline scenario is shown in Table 5. In Scenario 1, the carbon tax levy will result in carbon tax revenue of approximately 0.45 and 0.48 trillion Yuan in 2030 and 2035, respectively. However, due to the distortion of tax, there will be an economic downturn and other tax revenue sources all decrease. Aggregate government tax revenue shows an uptick, rising 1.29 % and 1.01 % in 2030 and 2035, respectively. As noted above, the carbon tax levy would damage economic efficiency; therefore, both household and enterprise incomes decline, with household and enterprise income decreasing by 0.25 % and 0.27 %, respectively in 2030. When the carbon tax rate is raised (Scenario 2), government tax revenue increases, but household and enterprise incomes decline further.

NED can promote economic growth and the incomes of various institutions also rise. In Scenario 3, government tax revenue will increase by 0.23 % and 0.08 % in 2030 and 2035, respectively and all types of tax revenue will also increase. Benefitting from the economic growth from the expansion of new energy investments, both household and enterprise incomes also rise. In Scenario 3, household income will increase by 0.36 % and 0.12 % in 2030 and 2035, respectively and enterprise income will increase by 0.21 %

Table 5
Change rate of economic growth under different policy scenarios relative to the baseline scenario.

Year	Scenario	Government tax revenue					Household income	Enterprise income
		Total	Carbon tax	Other production taxes	Personal income tax	Enterprise income tax		
2030	Baseline (trillion Yuan)	28.35	0.00	19.37	2.38	6.60	103.21	56.83
	Scenario 1	1.29 %	0.45	−0.26 %	−0.24 %	−0.34 %	−0.38 %	−0.34 %
	Scenario 2	3.80 %	1.31	−0.78 %	−0.70 %	−0.99 %	−1.12 %	−0.99 %
	Scenario 3	0.23 %	0.00	0.23 %	0.30 %	0.21 %	0.36 %	0.21 %
	Scenario 4	−0.57 %	0.00	−0.57 %	−1.03 %	−0.41 %	−1.10 %	−0.41 %
	Scenario 5	−0.57 %	0.00	−0.57 %	−1.03 %	−0.41 %	−1.10 %	−0.41 %
	Scenario 6	0.91 %	0.41	−0.53 %	−0.85 %	−0.49 %	−0.99 %	−0.49 %
	Scenario 7	−0.35 %	0.00	−0.35 %	−0.74 %	−0.20 %	−0.74 %	−0.20 %
2035	Baseline (trillion Yuan)	37.19	0.00	25.41	3.09	8.69	133.38	74.87
	Scenario 1	1.01 %	0.48	−0.27 %	−0.27 %	−0.37 %	−0.43 %	−0.37 %
	Scenario 2	2.95 %	1.42	−0.80 %	−0.79 %	−1.10 %	−1.27 %	−1.10 %
	Scenario 3	0.08 %	0.00	0.08 %	0.10 %	0.07 %	0.12 %	0.07 %
	Scenario 4	−1.29 %	0.00	−1.29 %	−2.43 %	−0.86 %	−2.56 %	−0.86 %
	Scenario 5	−1.44 %	0.00	−1.44 %	−2.73 %	−0.95 %	−2.87 %	−0.95 %
	Scenario 6	−0.52 %	0.41	−1.60 %	−2.83 %	−1.25 %	−3.12 %	−1.25 %
	Scenario 7	−1.42 %	0.00	−1.43 %	−2.71 %	−0.93 %	−2.84 %	−0.93 %

and 0.07 %, respectively.

CCC has a significant negative impact on the economy and the incomes of various institutions decline. In Scenario 5, all kinds of revenue declines relatively. Government tax revenue will decline by 0.57 % and 1.45 % in 2030 and 2035, respectively; both household and enterprise income will also decline, by 1.10 % and 0.41 %, respectively in 2030 and institutional income will decline further over time, by 2.87 % and 0.95 %, respectively in 2035.

Although the combined policy with carbon tax can slow down the decline of government revenue, it will lead to a greater decline in household and corporate income. In Scenario 6, government tax revenue will increase by 0.91 % in 2030 due to the carbon tax levy. Then, resulting from the further impact of the economic downturn, other tax revenue will continue to decrease by 0.52 % in 2035 compared with the baseline scenario. Overall, despite the fact that government revenue declines less in Scenario 6, other tax revenue, household income and enterprise income are lower than those in Scenario 7, indicating that policy with carbon tax is not conducive to raising household and enterprise income.

6. Conclusion and policy implications

Based on the data from the China Input–Output Table and the China Energy Statistics Yearbook, this paper uses the CGE model to simulate two types of environmental regulation policies, energy supply policy and carbon tax policy, comparing the environmental and economic effects of the two types of policies. The following are the conclusions drawn from the analysis:

The environmental effect of carbon tax policy is limited and carbon tax policy alone is not sufficient to achieve China's 2030 carbon peaking target. ① A simple carbon tax policy can produce a green dividend effect. A 40 Yuan/tonne carbon tax levy will lead to a finite decline in carbon emissions of about 1.10 % in 2030. In addition, a carbon tax will inhibit economic growth and fail to provide a blue dividend, resulting in a 0.22 % GDP decline and a 0.05 % decline in manufacturing value added by 2030. With the exception of carbon tax revenue, which contributes 0.45 trillion Yuan, all other tax revenue will decline and household and enterprise incomes will also decline. ② Raising the carbon tax rate can further reduce carbon emissions. When the carbon tax is raised to 120 Yuan/tonne, the carbon emissions in 2030 will drop by about 3.23 %, but no inflection point is reached for carbon emissions to achieve the carbon peaking target in 2030. At this time, the carbon tax levy will exert a larger burden on the economy, with a 0.64 % decline in GDP and a 0.05 % decline in manufacturing value added by 2030, and further declines in household and enterprise incomes.

The effects of energy supply policy must be analysed by policy type. ①The policy of NED can increase the total energy supply, promote economic growth and enhance the income levels of government, households and enterprises; however, the substitution effect on fossil energy is limited and cannot reduce carbon emissions. ②The policy of CCC has a positive impact on carbon emissions reduction. Only if coal consumption decreases by 1.5 % per year after 2031 compared with the previous year, will the 2030 carbon peaking target be realised. However, the simple CCC scenario (Scenario 5) will be more detrimental to the economy, resulting in a considerable energy shortage, with a 4.82 % decline in total energy consumption in 2030 and will inhibit economic growth, with a decline in income levels for all institutions.

When the policy of CCC is combined with NED, it is still possible to achieve China's 2030 carbon peaking target. In addition, it can also alleviate the pressure of economic downturn to a certain extent and the decline of institutional income is also slightly narrowed. However, when the combination of carbon tax policy and energy supply policy is implemented, the carbon emissions effect does not improve significantly relative to the energy supply policy alone, as economic downward pressure rises, especially the manufacturing value added falls significantly, and institutional revenue further declines. This demonstrates that the environmental effect of carbon tax policy is weakened when carbon tax policy is overlapped with energy supply policy. It also fails to alleviate economic downward pressure and increases enterprises' tax burden. Based on the results of this study, combined with the background of cutting taxes and fees in China, this paper predicts that China will not impose a carbon tax in the near future. China predominantly relies on energy supply policy to achieve its carbon peaking target. Policymakers will continue to implement NED and CCC.

Based on the conclusions above and in light of China's current energy planning, to effectively achieve the 2030 carbon peak target, the following recommendations are proposed:①The key to achieving China's carbon peak goal lies in controlling coal consumption. Strictly limit the increase in coal consumption before 2030, and reduce coal consumption by at least 1.5 % annually after 2030 compared to the previous year. ②Due to restrictions on coal consumption affecting energy supply, China needs to vigorously develop non-fossil energy sources and implement the " Action Plan for Carbon Dioxide Peaking Before 2030". By 2035, annual additional installed capacities are required as follows: 35 million kilowatts for wind power and 31.51 million kilowatts for solar power, while hydropower and nuclear power need to add 9.5225 million kilowatts and 4.0625 million kilowatts respectively per year. ③Carbon taxation should not be imposed in the short term. According to our simulation analysis, the imposition of a low-rate carbon tax has limited effectiveness in reducing carbon emissions. Imposition of a high-rate carbon tax, meanwhile, would have a significantly adverse impact on economic growth, and the reduction in carbon emissions would be modest, thereby offering a relatively limited contribution to achieving the 2030 carbon peak target.

Data availability statement

Data will be made available on request.

CRediT authorship contribution statement

Cong Wang: Writing – original draft, Visualization, Validation, Investigation, Data curation, Conceptualization. **Haisheng Hu:**

Writing – review & editing, Writing – original draft, Software, Project administration, Funding acquisition, Formal analysis.

Declaration of competing interest

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